Thermal Environment evaluation in commercial kitchens

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Introduction

Today there are no specific regulations or even parameters to guarantee that the thermal conditions in commercial kitchens are either comfortable or cost-effective; general evaluation criteria for thermal comfort may be inadequate and unsuitable for practical application. Thermal conditions of the working environment in commercial kitchens are primarily driven by radiant heat which directly impacts the employees. Moreover, appliances, size and arrangement of the kitchen zones, number of employees, variable environmental conditions during business hours, etc., complicate further an evaluation of the indoor thermal environment in kitchens. Based on standardised methods, a procedure for collecting data for the physical environment and subjective reactions in commercial kitchens is presented in this paper. The thermal strain on the occupants was not measured. On a few subjects the heart rate was measured as an indicator of the metabolic rate during a working day. This procedure has been used in a larger study of the indoor environment in more than 100 commercial kitchens. The procedure and main results are presented in this paper.

Evaluation of the thermal environment in commercial kitchens

For many years the international Standard Organisation (ISO) and ASHRAE have been developing standards for the indoor thermal environment. ASHRAE has mainly developed standards for moderate thermal environments (ASHRAE-55 [1]) while ISO standards cover the range from cold stress to comfort to heat stress (ISO EN 7730 [2], ISO EN 7933 [3], ISO EN 11079 [4]).

As the commercial kitchen environment presents different conditions than those studied earlier, a measuring procedure was established focusing in particular on the processes characterising the kitchen space. For example, employees facing high-energy appliances, such as an under-fired char broiler, ovens, steamers, deep-fat fryers, or to bursts of very humid hot air, are subject to higher radiant conditions than employees working on a preparation line with their backs a few feet from the appliances.

Methods

Data collection includes several types of measurement: external air temperature and humidity, HVAC-system (heating, ventilation and air conditioning) performance (supply, make-up, and transfer air temperature and relative humidity), indoor (thermal) environment, physiological and subjective evaluation. The intention was to collect data for the physical environment (physical parameters) and personal factors such as clothing and activity, to be able to calculate existing indices for evaluation of thermal comfort and/or heat stress.

Therefore, three different kitchen zones (cooking, food preparation, and dish-washing) were measured; these being considered to have different thermal conditions in the commercial kitchen. Loggers were installed for one week (1st walk in) to record kitchen operative and air temperatures (t_o and t_a) and relative humidity (RH) in time interval of 15 minutes. Other recording devices were used for more detailed spot measurements (2nd

walk in) of thermal parameters (air temperatures, humidity, air velocity, and radiant temperatures) close to the working position of the employees and at different heights during the peak operating hours of one working day (breakfast, lunch, and/or dinner time).

Instrumentation

Air temperatures, air velocities, globe temperatures and plane radiant temperatures were measured in three heights (0.1, 1.1 and 1.7m above floor). These measurements, together with relative humidity (accuracy ±2.5%), were stored in small data loggers.

The air temperature (t_a), plane radiant temperature (t_{pr}) and operative temperature (globe, t_o) (sensors were built according to the results of Simone et al. (2007) [5] obtained by experimental laboratory work and described in ISO 7726 [6]. Both temperature sensors have an accuracy of ±0.3°C in the range of 10°C to 40°C. An omnidirectional anemometer was used for measuring air velocity. It can measure across a range from 0.005 to 5 m/s, with an accuracy of 0.02 m/s ±1% of readings. All physical parameters of the investigated environment were recorded with a maximum frequency of one second.

Evaluation of clothing and metabolism

The thermal resistance and evaporative resistance of clothing can be estimated by ISO 9920/2006 [7]. In particular, during the spot measurements, researchers estimated the level of workers' clothing insulation as the sum of the individual values of various garments as listed in Table B.2 of the ISO9920/2006 [7].

The metabolic rate can be estimated by ISO 8996/2004 [8], taking into account the type of work. The activity level in a kitchen changes a lot during a working day, so it is recommended to estimate a time-weighted average during the previous hour. During the measuring time in the commercial kitchens, the employees´ activity level was estimated by "*observation*" and by "*analyses*" with the assessed employee heart rate of one or more individuals within each kitchen, together with their age, weight and sex.

Subjective response (questionnaires)

During the field studies the subjects were asked to fill in two questionnaires (based on ISO 10551/2001 [9]); one on long-term general effects and one on occupants' immediate reactions, used to evaluate thermal and working conditions, to support physical data monitoring and to analyse the relationship between the physical parameters of the environment and subjective aspects of the occupants' perception of thermal comfort in the kitchen environment. To minimise disturbance for the employees, the few questions related to the instant environment perception were verbally asked and recorded electronically by the investigator. An exception was needed for the evaluation of the thermal sensation collected by using the 7-points thermal sensation scale (Figure 1). In fact, the employee at his working station was asked to look at the scale and indicate his/her thermal perception was at that instant. The employee was asked to use it as a continuous scale.

Figure 1. Seven points Thermal Sensation scale

Several other questions, dealing with the working conditions and environment in general, including some facts about the person (like: age, weight, etc.), were reported in the long term questionnaire which consists of eight parts: Background characteristic, Personal comfort, Personal control, Work conditions, Work area satisfaction, Health characteristic, Environment sensitivity, and Occupants´ clothing.

Results

Several results of this study of 100 kitchens are presented here.

In the study of thermal environment in commercial kitchens, one-week measurements at three locations were measured in all kitchens, in both summer and winter. Spot measurements of thermal parameters at three heights and at three locations, together with subjective evaluations, were performed in 39 kitchens during the summer monitoring phase and in 35 kitchens during winter, totaling 373 respondents.

It was not possible to find a temperature where everyone was satisfied. However in 5 K range of operative temperature, the lowest level of dissatisfaction was about 11% at an operative temperature around 20-25 °C. The dissatisfaction increases progressively on both sides of this range.

To investigate the relation between the thermal sensation votes (TSV) in the Kitchen and the percentage of dissatisfied employees (PD), the TSV values were grouped in ranges. In this way, having a critical number of subjects in each range, % of dissatisfied can be estimated. Figure 2 shows a strongly polynomial relation (R^2=0.98) between TSV and the % dissatisfied, reported as equation 1.

$$\mathrm{PD}(\%) = 5.102 \cdot f(TSV)^2 - 40.247 \cdot f(TSV) + 84.124 \qquad R^2 = 0.98 \tag{1}$$

The polynomial relation TSV-PD (Figure 2) shows similarities with the PMV-PPD (Predicted Mean Vote-Predicted Percentage Dissatisfied) curve (Fanger, 1970 [11]) with the same minimum at 5% for TSV=0. The increase in %-dissatisfied with increasing TSV is however much lower than the PMV-PPD relation.

In a significant number of measuring positions, the thermal conditions (mean radiant temperature) were out of the range for using the PMV-index and resulted in PMV-values outside the range ± 3.

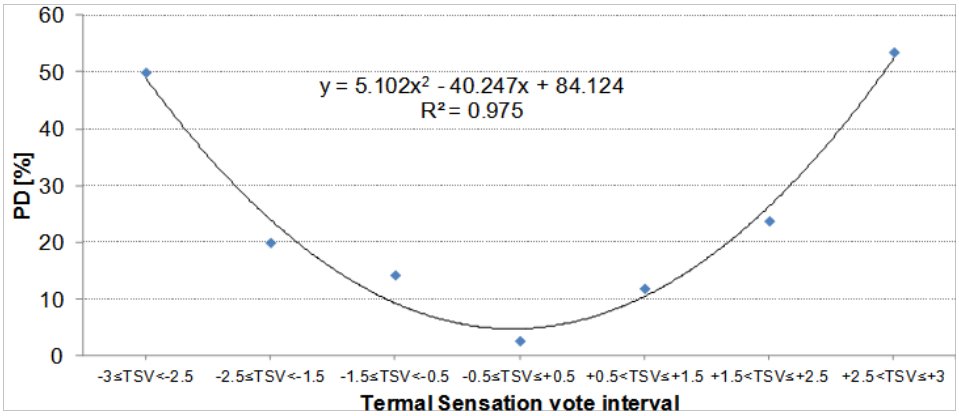

Figure 2. Dissatisfaction versus Thermal Sensation

CONCLUSIONS

A recommendation for measuring locations and type of sensors to use, and a method and a procedure for evaluating the indoor thermal environment in commercial kitchens was established and used in 100 commercial kitchens.

Especially due to the high thermal radiation from the appliances in the cooking zone the measured conditions were in many cases outside the range of the PMV-index (ISO EN 7730)

From the measurements a first estimation of a thermal comfort range for commercial kitchens workspace was given as the interval of operative temperature of 20-25 °C (68-77 °F) corresponding to 11% of dissatisfied employees. Besides, a strong quadratic relation was estimated between the TSV and percentage dissatisfied.

Acknowledgement

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